

EFFECTS OF HIGH-DENSITY IMPACTS ON SHIELDING CAPABILITY

Eric L. Christiansen¹ and Dana M. Lear²

¹NASA Johnson Space Center, Mail Code KX, 2101 NASA Parkway, Houston, TX 77058,
Eric.L.Christiansen@nasa.gov

²NASA Johnson Space Center, Mail Code KX, 2101 NASA Parkway, Houston, TX 77058,
Dana.M.Lear@nasa.gov

ABSTRACT

Spacecraft are shielded from micrometeoroids and orbital debris (MMOD) impacts to meet requirements for crew safety and/or mission success. In the past, orbital debris particles have been considered to be composed entirely of aluminum (medium-density material) for the purposes of MMOD shielding design and verification. Meteoroids have been considered to be low-density porous materials, with an average density of 1 g/cm³. Recently, NASA released a new orbital debris environment model, referred to as ORDEM 3.0, that indicates orbital debris contains a substantial fraction of high-density material for which steel is used in MMOD risk assessments [Ref.1]. Similarly, an update to the meteoroid environment model is also under consideration to include a high-density component of that environment. This paper provides results of hypervelocity impact tests and hydrocode simulations on typical spacecraft MMOD shields using steel projectiles. It was found that previous ballistic limit equations (BLEs) that define the protection capability of the MMOD shields did not predict the results from the steel impact tests and hydrocode simulations (typically, the predictions from these equations were too optimistic). The ballistic limit equations required updates to more accurately represent shield protection capability from the range of densities in the orbital debris environment. Ballistic limit equations were derived from the results of the work and are provided in the paper.

Several MMOD shields were tested and evaluated during the course of this work including:

- Whipple shields with relatively short standoffs (< 2cm) and containing an outer multi-layer insulation (MLI) thermal blanket, aluminum bumper and aluminum rear wall. These shields are used to protect certain visiting vehicles to the International Space Station (ISS).
- Whipple shields with longer standoffs (10cm-15cm) between an aluminum bumper and aluminum rear wall.
- Stuffed Whipple shields which contain ceramic fabric and Kevlar fabric between the outer aluminum bumper and rear wall.

Tests have been performed at NASA White Sands Test Facility (WSTF) using two-stage gas guns to 7.5 km/s and at University of Dayton Research Institute (UDRI) using a three-stage launcher to 10 km/s. Both facilities use sabot techniques to launch spherical projectiles, measure impact velocities to ± 0.015 km/s or better, and verify projectile integrity prior to impact. Figure 1 illustrates front and side views from high-speed cameras during a typical impact on an MMOD shield at WSTF. Hydrocode simulations were performed by Dr. Fahrenthold at the University of Texas at Austin using the EXOS hybrid particle-element code.

Figure 2 provides results from impact tests using steel projectiles at 30 deg impact angle on short-standoff Whipple shields compared to results with aluminum projectiles. Failure criteria of these tests is a through-hole or through-crack in the aluminum rear wall of the shield. Steel projectiles are several times more penetrating on a mass basis than aluminum projectiles. For instance at 7 km/s and normal impact angle (0 deg), a 1.0mm diameter spherical steel projectile (0.0041g) is at the rear wall perforation limit for a short-standoff shield compared to a 2.24mm

diameter aluminum projectile (0.0165g) causing the same level of shield damage. Similar results were obtained at 45 deg and 60 deg impact angles. The ballistic limit equations derived from the work are used in MMOD risk assessments for NASA spacecraft.

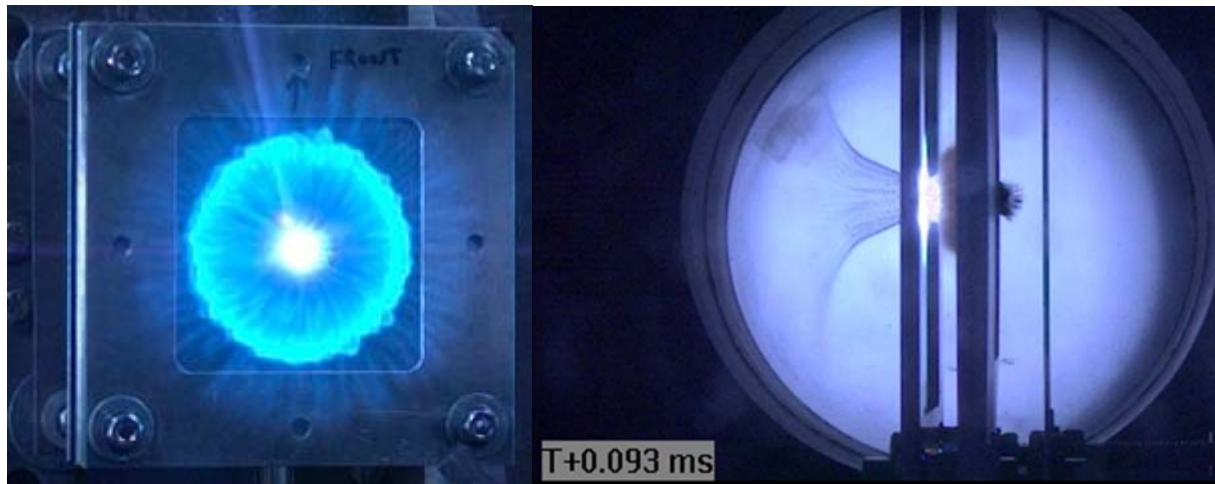


Figure 1. Test HITF-12200, side view at top (impact direction is left to right), and front view on bottom, showing debris cloud and impact flash 0.01ms after impact

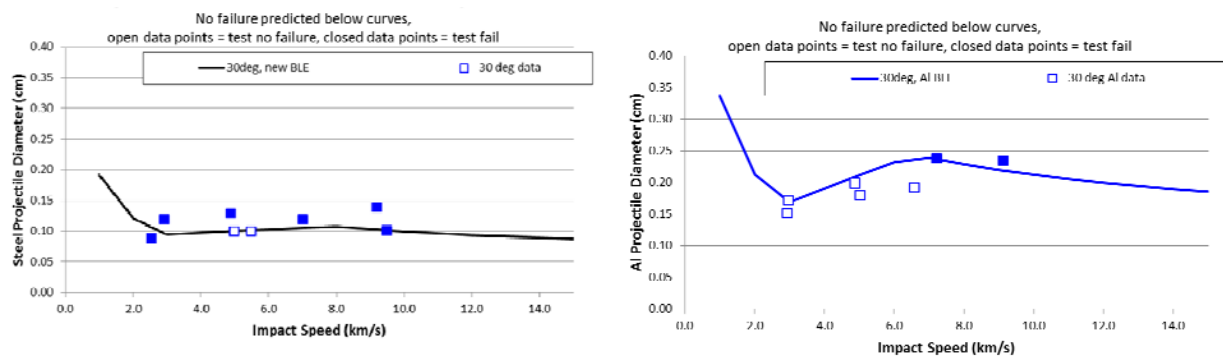


Figure 2. Short-standoff Whipple BLE Prediction compared to steel projectile test data (on Left) and aluminum projectile test data (on Right) at 30 Degree Angle

References

1. NASA/TP-2014-217370, NASA Orbital Debris Engineering Model ORDEM 3.0 - User's Guide, 2014.